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Some Principles of Construction of Water Resistant Fabrics

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PROTECTION from rainfall is an essential requirement of the combat uniform. Under conditions such as exist in Korea during the early Spring and late Fall, and especially in the freezing rainfall of winter, the ability to keep the insulating layers of the uniform dry is basic to the fighting efficiency of the combat soldier. The simplest solution for keeping rain out of the clothing under these conditions is to use a thin waterproof outer layer. However, because of its impermeability, such a layer reduces heat losses to a point where the body approaches a condition of heat stress, and in addition, prevents the dissipation of perspiration so that the inner layers of clothing become wet, even though no rain has leaked through the raincoat. At lower temperatures the presence of moisture in the clothing, heated by the body, may lead to dangerous evaporative cooling.

Considerable research effort has been devoted to finding a fabric which is completely impermeable to rainfall from without, and yet is moisture vapor permeable from within. Although no completely satisfactory solution to this problem has been found, the development of high textured wind resistant, water repellent fabrics such as the high sley oxfords originally developed at the Textile Institute in Manchester, England, came close to meeting these requirements. The addition of the water repellent treatment does not reduce the permeability of fabrics to water vapor and thus these materials can be worn continuously without interfering with the normal evaporation of perspiration from the skin.

Double Layer Principle

A marked advance in the utilization of permeable type water repellent fabrics came with the introduction of the double layer principle, where it was found that the effective resistance to penetration of two adjacent layers of water repellent

Fig. 1—Garment of a test subject on the rain course of the Quartermaster Board at Ft. Lee, Va., being examined for signs of failure.

fabric was four to five times that of either layer by itself. Many water repellent garments and jackets procured by the armed services at the present time take advantage of this double layer principle.

A basic understanding of the factors contributing to the water resistance of textile structures has been made possible by a recent important testing innovation whereby it has been found that, under specified conditions, natural rainfall can be simulated in the three important parameters of intensity, drop size and drop velocity. The development by the Quartermaster Laboratories of a series of nozzles[1] for this purpose installed in a "rain room" has facilitated the development of fabrics and combinations of fabrics of superior water resistance. An extensive rain course, making use of these nozzles, was set up by the Quartermaster Board at Fort Lee, Va. This course is used for final acceptance and approval of the design of water resistant fabrics and garments prior to standardization and procurement by the Quartermaster Corps. Figure 1 shows the garment of a test subject being examined for signs of failure on one of the sections of the rain course at Fort Lee.

Influence of Construction

With the development of the rain room and newer laboratory instruments for evaluating water repellency, the Quartermaster Laboratories made

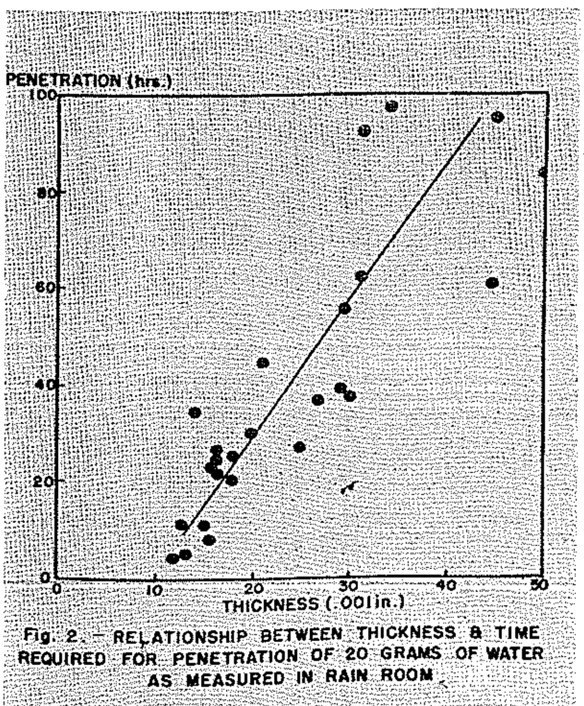

Fig. 2.—RELATIONSHIP BETWEEN THICKNESS & TIME REQUIRED FOR PENETRATION OF 20 GRAMS OF WATER AS MEASURED IN RAIN ROOM

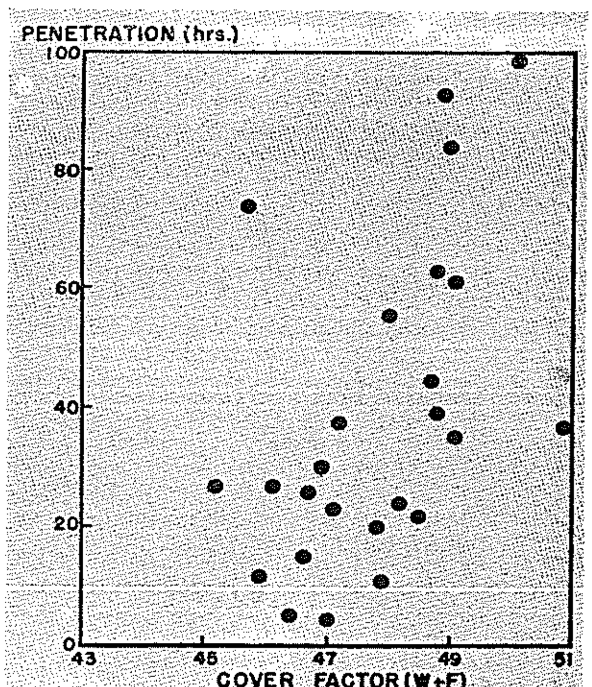

Fig. 3.—RELATIONSHIP BETWEEN COVER FACTOR (WARP + FILLING) & TIME REQUIRED FOR PENETRATION OF 20 GRAMS OF WATER AS MEASURED IN RAIN ROOM

a detailed investigation of the effect of variations in fabric structure on the water resistance of textile materials. The data obtained in this study have furnished a vital clue to the engineering of water resistant structures by revealing that thickness (which has been shown to be extremely important for wear resistance) and "tightness" are two most important factors to be considered in the design of water resistant fabrics. In carrying out this work a series of fabrics was designed based on the principles established by Dr. F. T. Peirce.[2] The fabrics were made in the oxford weave, as originally developed by Dr. Peirce, from combed, plied, mercerized cotton yarns of low twist. The yarns varied in size from 80/2 to 5/3 and the textures of the fabrics from 47 X 21 to 200 X 95. The weights varied from approximately 6 to 25 ounces per square yard and thicknesses ranged from 0.012 to 0.045 inch. After weaving, the fabrics were desized, scoured, treated with a durable water repellent and Sanforized in full commercial lots.

The fabrics were originally designed for maximum "tightness" or to have maximum cover factors, K, as defined by the following formula:

$$K = \frac{\text{yarns per inch}}{\sqrt{\text{count}}}$$

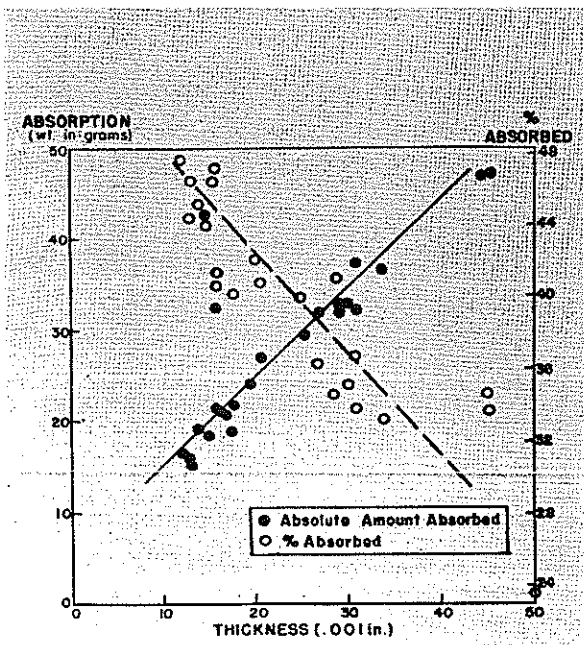

Fig. 4.-RELATIONSHIP BETWEEN FABRIC THICKNESS & ABSORPTION AS MEASURED IN RAIN ROOM.

After finishing it was found that the cover factors varied from 26.6 to 32.5 in the warp and from 13.6 to 19.0 in the filling with the combined cover factor representing the sum of the warp and filling cover factors for individual fabrics ranging from 44.0 to 51.2. Throughout this work the sum of warp and filling cover factors was used as a measure of fabric tightness because it was found to correlate well with both laboratory and field evaluations. Only those fabrics which were shown to be uniformly treated with water repellent were analyzed in this study so that the comparisons made indicate only the contribution of structure to the water resistance of the fabric. Some of the major effects noted in analyzing this series of fabrics in the rain room at the Quartermaster Laboratories in Philadelphia and on standard laboratory test instruments are briefly described herein:

Rain Room Evaluation

Resistance to penetration in the rain room was evaluated by observing the time required for 20 grams of water to penetrate the fabric as measured by the increase in weight of a backing material mounted on a hemicylindrical form under the test fabric.[3] It was found that the two most important factors governing penetration by simu-

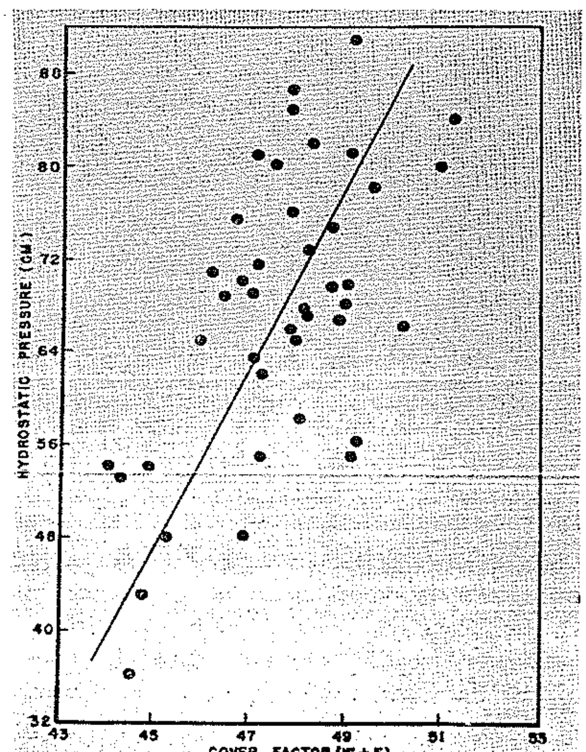

Fig. 5. RELATIONSHIP BETWEEN HYDROSTATIC PRESSURE AND COVER FACTOR. (WARP + FILLING)

lated rainfall are thickness and tightness of the fabric structure. Figure 2 shows that the time required for water to penetrate the fabric increases linearly with thickness, more than doubling for a twofold increase in thickness. Figure 3 shows the relationship between penetration in the rain room and fabric tightness. The rapid increase in resistance to penetration, as the sum of the warp and the filling cover factors is increased above 45, indicates that there is a critical tightness of weave necessary for water resistant fabrics.

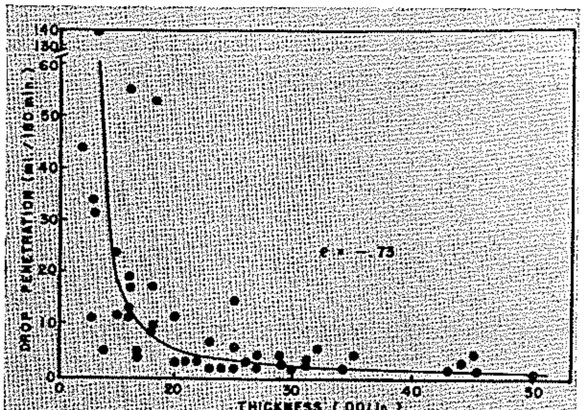

Fig. 6 RELATIONSHIP BETWEEN THICKNESS & DROP PENETRATION OF 47 FABRICS

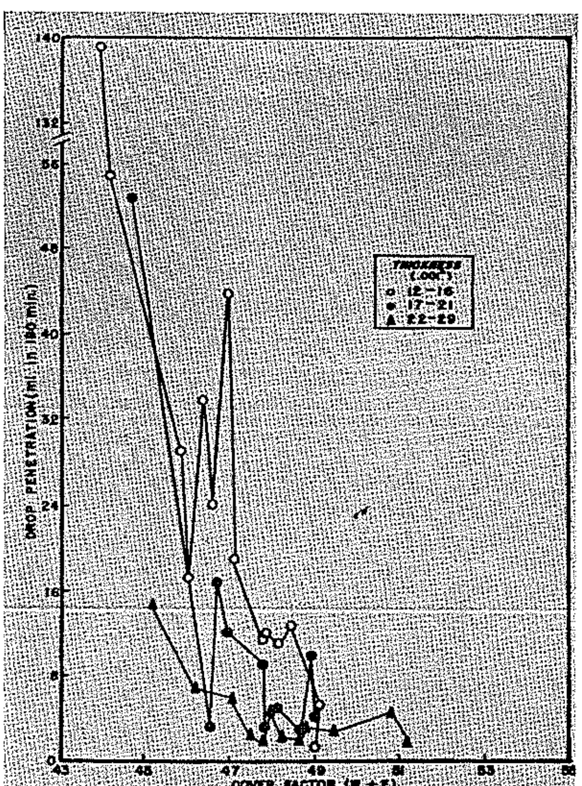

Fig. 7 RELATIONSHIP BETWEEN DROP PENETRATION AND COVER FACTOR (WARP + FILLING) WITHIN THICKNESS GROUPS

Simulated rainfall tests also demonstrate that the amount of water absorbed by a fabric is a function of its thickness. The greater absorption of thicker fabrics as shown in Figure 4 reflects the increase in absorbing surface provided by the larger yarns. However, it should be noted that although this is true based on the absolute amount of water absorbed per unit area, the thicker fabrics actually absorb less water on a weight percentage basis. It is felt that lower absorption based on fabric weight is of more significance from the standpoint of comfort than lower absorption of water based on fabric area.

Laboratory tests showed trends similar to those noted for simulated rainfall; although it was found that some laboratory tests, such as hydrostatic resistance[4] and dynamic absorption,[4] reflect the importance of individual fabric properties on water resistance, while others, such as the drop penetration,[4] indicate the influence of groups of properties more like simulated rainfall. For example, as shown in Figure 5, resistance to hydrostatic pressure increases linearly as the sum of the warp and filling cover factors increases. However, a significant relationship between hydrostatic resistance and thickness does not exist. On the other hand, dynamic absorption decreases as the thickness of the fabric increases but is much less affected by changes in the tightness of the fabric.

Limitations of Lab Devices

Typical laboratory penetration devices such as the duPont rain tester[5] and the drop penetration apparatus exhibit marked curvilinear relationships when penetration is plotted against thickness. For example, in Figure 6, which shows the relationship between drop penetration and thickness, it may be noted that a very rapid change in the slope of the curve takes place at approximately 0.020 inches, which is in the fabric thickness range of most interest for lightweight water resistant fabrics. This is unfortunate and seriously limits the use of this type of equipment as a means of evaluating the effective water resistance of textile materials. The duPont rain tester shows a similar change in slope at approximately 0.020 inches. However, the penetration devices are similar to simulated rainfall in showing the effect of fabric "tightness" on penetration. It may be noted in Figure 7 that a rapid increase in resistance to penetration occurs as the cover factor sum exceeds 45.

In the absence of more refined evaluation techniques, the standard hydrostatic resistance test may be used as an index of the contribution of tightness and the dynamic absorption test as an index of the contribution of thickness to the effective water resistance of textile fabrics. Thus, a simultaneous increase in hydrostatic resistance and a decrease in dynamic absorption indicates probable improved resistance to rain penetration in use.

Based on the results of the analysis of these data, it appears that for effective water resistance, fabrics should be constructed to have a cover factor sum of 45 (for oxfords) as a minimum and should be as thick as possible consistent with the weight limitation of the proposed application. The use of coarse, low-density yarns is indicated to be an effective approach to making such fabrics.

Currently, a subcommittee of the National Research Council is working with our laboratory staff in Philadelphia to develop practical light-weight water resistant structures based on principles developed in studies such as this. The standard fabrics which are now used in such applications (Byrd cloth and oxfords) have serious limitations in that the tear strength in the filling direction becomes dangerously low as the tightness and cover of the fabric is increased. In addition, the fine combed yarns which are used in making these fabrics are in short supply at the present time and the armed services are having difficulty in obtaining sufficient capacity in industry to meet current demands for this type of material.

The work of the committee has been directed toward experimenting with fabric weaves which are inherently more tear resistant, such as the sateen and, in addition, utilizing single and carded yarns which are more readily available. A program is also in progress to include the use of synthetic fibers, especially in the filling direction of these fabrics. Some of the synthetics under consideration are subject to greater shrinkage during processing and will thus increase the tightness of the structure. Others, which are of higher strength than the natural fiber, will improve the tear strength of the fabrics. Further basic studies of the type described in this brief review are also under way to evaluate the relative contribution of yarn twist, spinning system and weave type on the inherent water resistance of textile structures.

References

1.—Landsberg, M. I., and Moody, F. "Device for Producing Artificial Rainfall for Tests of Water-Repellent and Water-Proof Materials"—Textile Research Journal *16*, 211-18 (1946).

2.—Peirce, F. T., "The Geometry of Cloth Structure",—Journal of Textile Institute *28*, T45-T96 (1937).

3.—Landsberg, M. I., Kelley, R. and Sinski, D. "Correlation of Simulated Rainfall Tests with Laboratory Penetration Tests".—Textile Research Journal *19*, 505-16 (1949).

4.—Federal Specification CCC-T-191A and Supplement.

5.—Technical Manual and Year Book of the American Association of Textile Chemists and Colorists (1947-1948).